Frequency-Based Monitoring of Small-Scale Explosive Volcanic Activity

Anna K. Worden[1]
Jonathan Dehn[2]
1) Alaska Volcano Observatory, Geophysical Institute, University of Alaska Fairbanks,903 Koyukuk Drive, Fairbanks, AK, 99709, (akworden@gi.alaska.edu)
2) Alaska Volcano Observatory, Geophysical Institute, University of Alaska Fairbanks,903 Koyukuk Drive, Fairbanks, AK, 99709, (jdehn@gi.alaska.edu)

Abstract

Strombolian activity is one of the most common types of volcanic activity. When this activity occurs at remote volcanoes it often goes undetected and cannot be monitored easily or safely by direct methods. Satellite remote sensing can be useful in the routine monitoring of this activity. Numerous remote volcanoes in the North Pacific exhibit Strombolian activity, often as a precursor to more vigorous activity which can affect communities and transportation. Factors affecting the visibility the explosions include satellite and crater geometry, time of image capture, and most importantly, weather. These factors eliminate a significant number of satellite passes. The remaining passes are used to calculate the probability of a clear view at the volcano and the likelihood of detecting an explosion. All of these factors are used to detect changes in relative frequency of explosions.

Introduction

In many cases in the North Pacific it is not feasible to deploy any ground-based monitoring system. Access to islands can be restricted by weather, cultural relevance, and geography. Satellite remote sensing becomes an invaluable tool in tracking volcanic activity. Multiple North Pacific volcanoes exhibit frequent explosive activity. This can be picked out in seismic records where available, but can go undetected on non-seismically monitored volcanoes. For this research Mt. Chuginadak (Cleveland), and Shishaldin in Alaska, and Karymsky in Russia have been chosen as characteristic small-scale explosive volcanoes (fig.1). Stromboli in Italy (fig.9) was also used as a type source for detection parameters.

The most telling characteristic of small-scale explosions is their transient nature. A FLIR Systems S40 thermal camera was used to recorded spatter fields from scaled lab explosions (fig.2) and actual strombolian explosions (fig.3). Both scaled and real data show that the material peaks at an initial temperature and then cools exponentially (fig.4). This transient nature can be seen in sets of consecutive satellite imagery (fig.5). A long-lived explosion or an eruption that deposits hot material will show a thermal signal in multiple consecutive passes and can last for days to weeks, depending on the temperature of the deposit and the environmental factors. A small-scale explosion has a much shorter lived signal, lasting perhaps only a few minutes.

The term "small-scale explosion" has been adopted here to deal with incongruities in classification schemes. Many of the explosions discussed can be classified as strombolian style explosions, driven by a gas slug which bursts when it reaches the magma free surface (fig.6). In some cases, the vent can become choked with cinders or a denser, more viscous plug. Pressure builds behind the plug which eventually fails, causing an explosion.

Ultimately, the mechanism causing small-scale explosions is not entirely critical. The deposition of hot ballistics onto the flanks or into the crater of the volcano is what will create a thermal signal on satellite imagery.

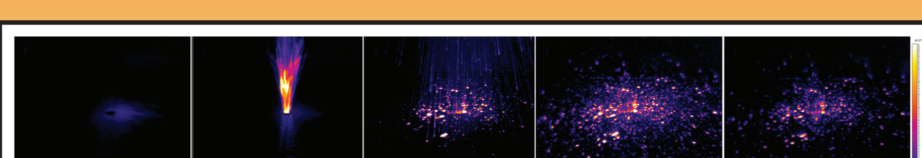


Figure 2: Honey spatter at 85°C from 2.9 cm diameter nozzle, corresponding to a 3.6 m diameter vent.

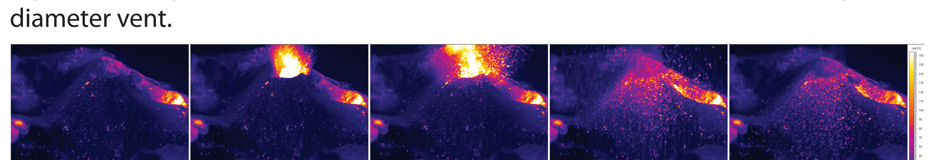


Figure 3: Explosive event at Stromboli Volcano in Italy. The vent is thought to be approximatley 4-5 m in diameter.

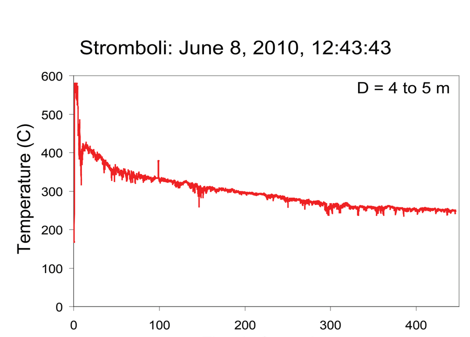
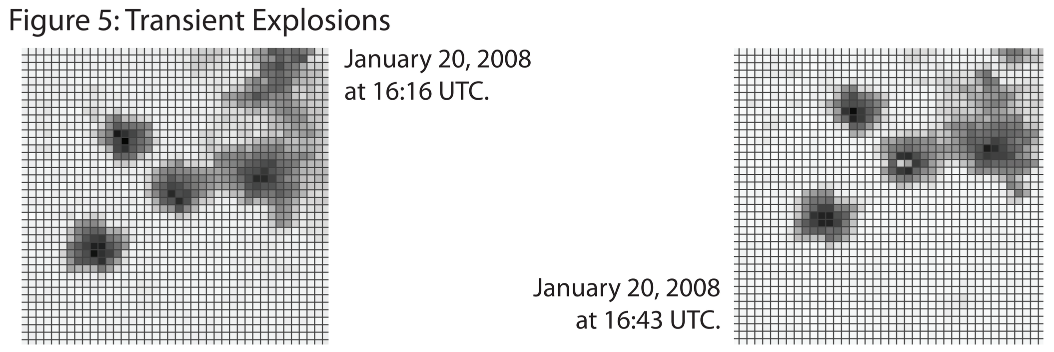


Figure 4: Cooling curves for an explosion at Stromboli Volcano illustrating the transient nature of small explosion thermal signals. The red line indicates the maximum temperature thermal signal.

Figure 5: Transient Explosions



These two images of Cleveland Volcano (Alaska) were collected 27 minutes apart. The first image is clear with no anomaly and the second image is clear with a well defined anomaly.

Figure 1: North Pacific location map.

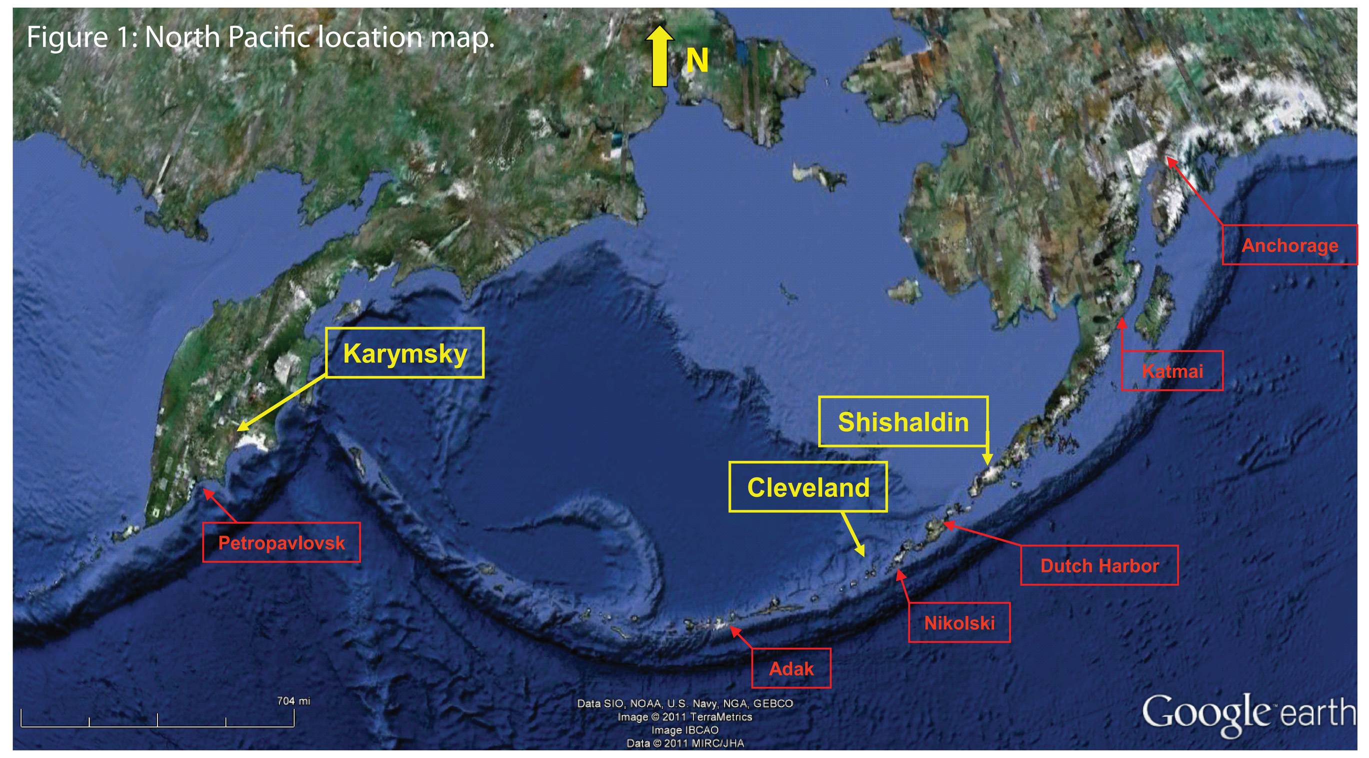


Figure 7: Images collected of Cleveland Volcano. Image (a) would be classified as Cloudy (100) and image (b) would be classified as Clear (0).

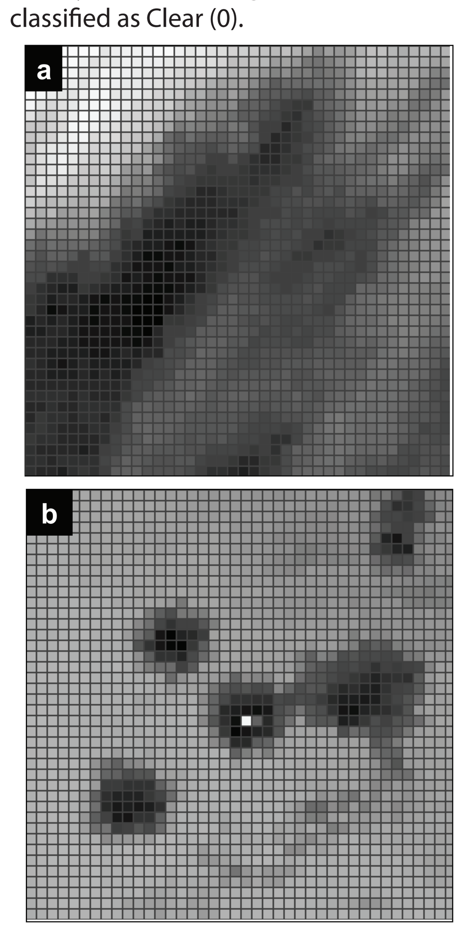


Figure 6: Strombolian Style Explosion

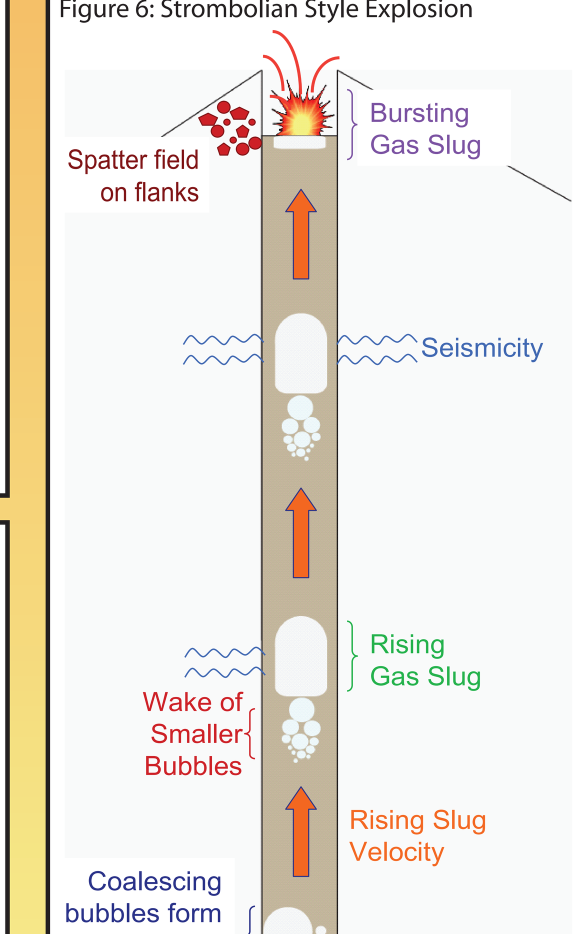
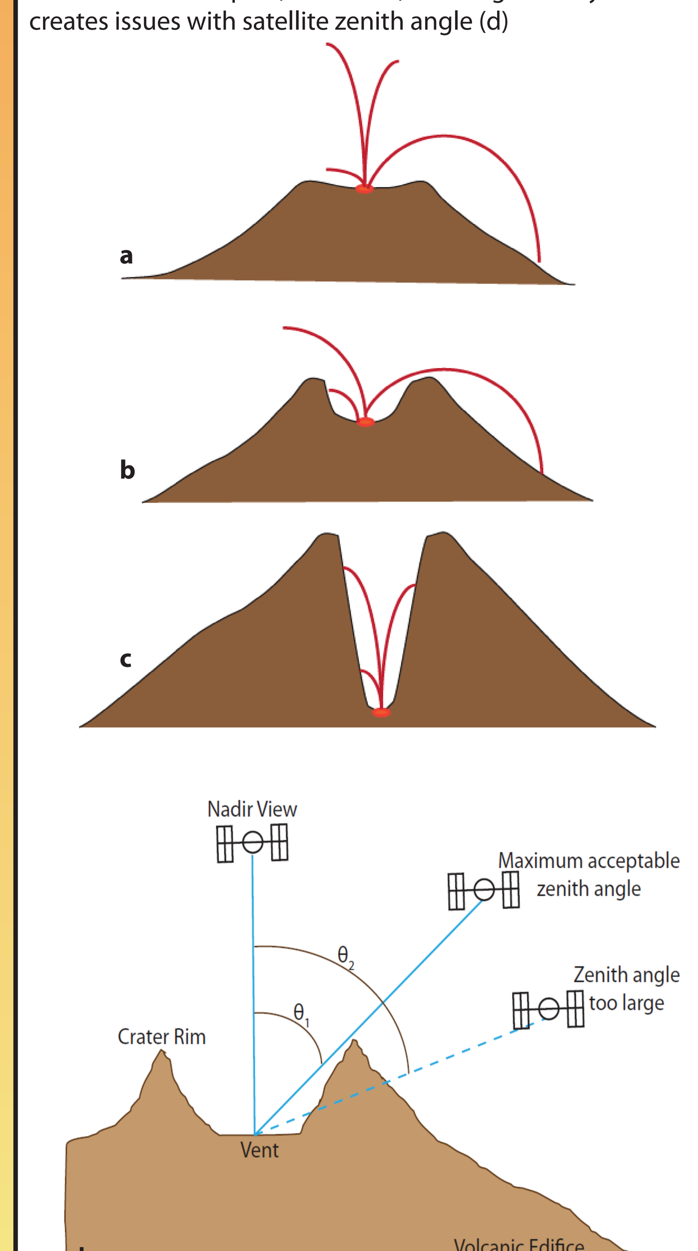


Figure 8: Crater to vent depths. Crater (a) would be 5-10 meters in depth (Stromboli, Karymsky). Crater (b) would be 10's-100 meters in depth (Cleveland). Crater (c) would be 100's of meters depth (Shishaldin). Crater geometry also creates issues with satellite zenith angle (d)



Methods

Data, Duplicates, and Non-Data

All data used has been stored by the Geographic Information Network of Alaska (GINA) and the Alaskan Volcano Observatory (AVO) after being collected by ground stations at the University of Alaska Fairbanks and Gilmore Creek Station in Fairbanks.

The AVHRR (Advanced Very High Resolution Radiometer) sensor is aboard multiple NOAA polar orbiting satellites. Channel 3 is used for detection of thermal anomalies, measuring in the mid infrared wavelengths (3.55-3.93 μm) at a spatial resolution of 1.1km. The MODIS (Moderate Resolution Imaging Spectroradiometer) sensor is aboard NASA's polar orbiting satellites, Terra and Aqua. Channels 20 and 22 are used for detection of thermal anomalies, measuring a spectral band comparable to channel 3 on the AVHRR sensor ; ch20 at 3.66-3.84 μm and ch22 at 3.93-3.99 μm. Both are collected at a spatial resolution of 1km.

In some cases duplicate images were saved from both receiving stations. These images would be saved some seconds apart, thus appearing unique, though they would contain identical data.

Incomplete data due to sensor, receiving station, or encryption error made up a small number of images. This resulted in data with NAN values. In some cases the entire image is useless, while in other there were only bands of incomplete data. Unusable images were removed from the dataset.

Satellite Zenith Angle - Swath

Two satellite zenith angles cut-offs were used to pare down the data. The first was a value of 40° to correspond with swath overlap. This insures that each pixel contains unique values and does not overly impact surrounding pixels (Patrick et al., 2005).

Satellite Zenith Angle - Crater

The other satellite zenith angle cut-off point was volcano specific (Cleveland = 25°, Karymsky =30°, Stromboli = 30°, Shishaldin = 25°) and was done to insure an unhindered view into the volcanoes crater, presumably to the vent. For a deeper, more steep sided internal crater, a lower satellite zenith angle is required to image the bottom of the crater (fig.10).

The topography of the volcanic edifice will also effect the pixel representation. A sensor view of a steep slope will be either shortened or lengthened (sometimes dramatically) depending on the direction of look .

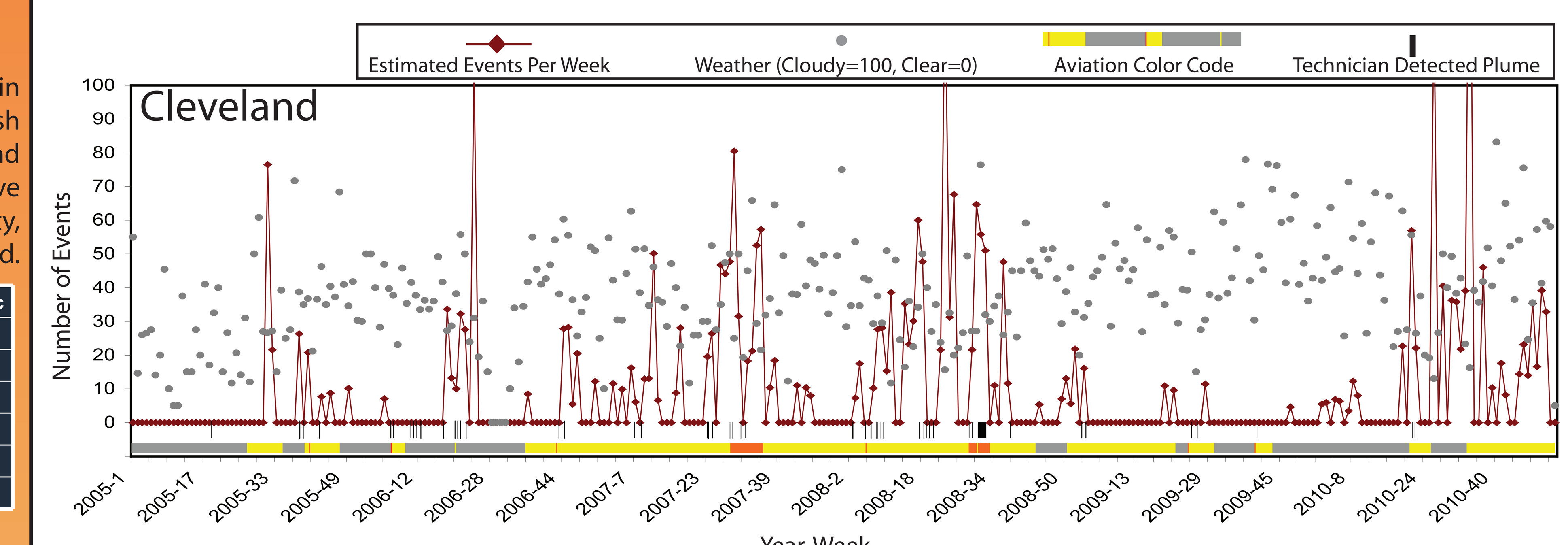
Weather

Weather can be the most significant hindrance when viewing thermal infrared data (fig.7). Each image was individually viewed to determine the weather in the area directly associated with the volcano and was assigned a grade (cloudy, mostly cloudy, partly cloudy, mostly clear, clear). After this step a weather statistic was calculated by averaging the assigned grades. This statistic was then used to calculate the probability of seeing a thermal anomaly in the satellite data.

Results

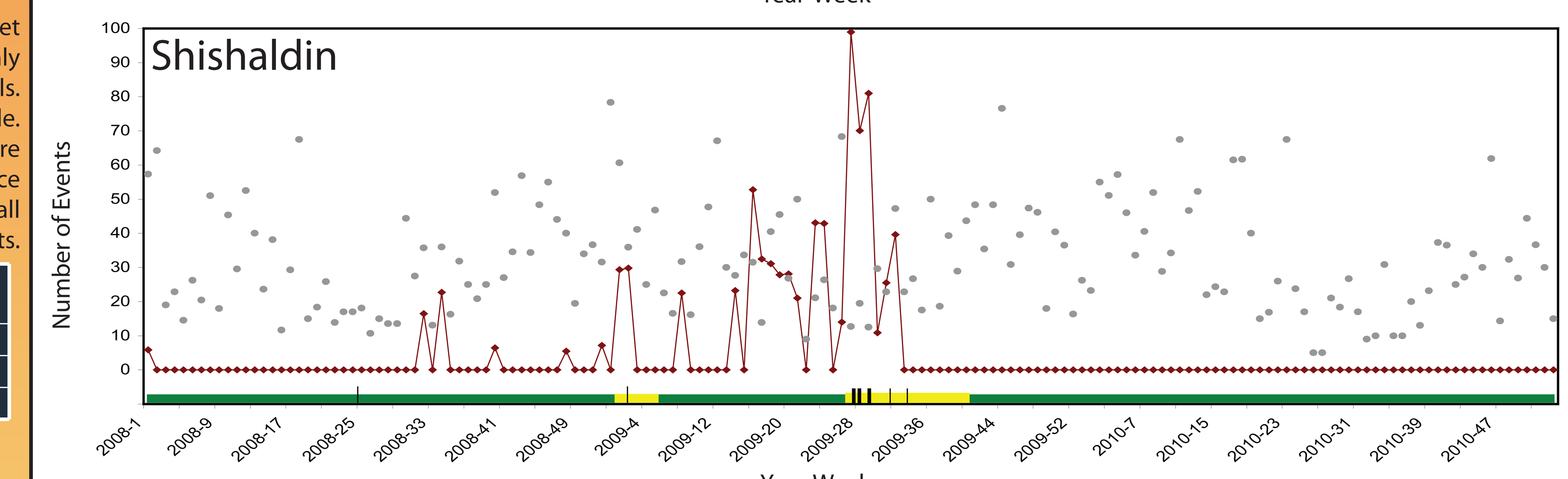
Cleveland is the most active volcano in the Aleutian chain in terms of both ash plumes and thermal signals. A total of 105 ash signals and 226 thermal anomalies were reported for Cleveland during the analyzed time period. An average of 10 explosive events per week, with distinct periods of heightened activity, was calculated for the analyzed period.

Year	Collected Images	Viable Images	Thermal Anomalies	Weather Statistic
2005	3565	384 *(10.7%)*	10	30.55
2006	6672	577 *(8.7%)*	31	34.5
2007	6502	520 *(8%)*	55	39.73
2008	7813	557 *(7.1%)*	56	36.12
2009	9454	688 *(7.3%)*	6	47.01
2010	5480	521 *(9.5%)*	68	43.36



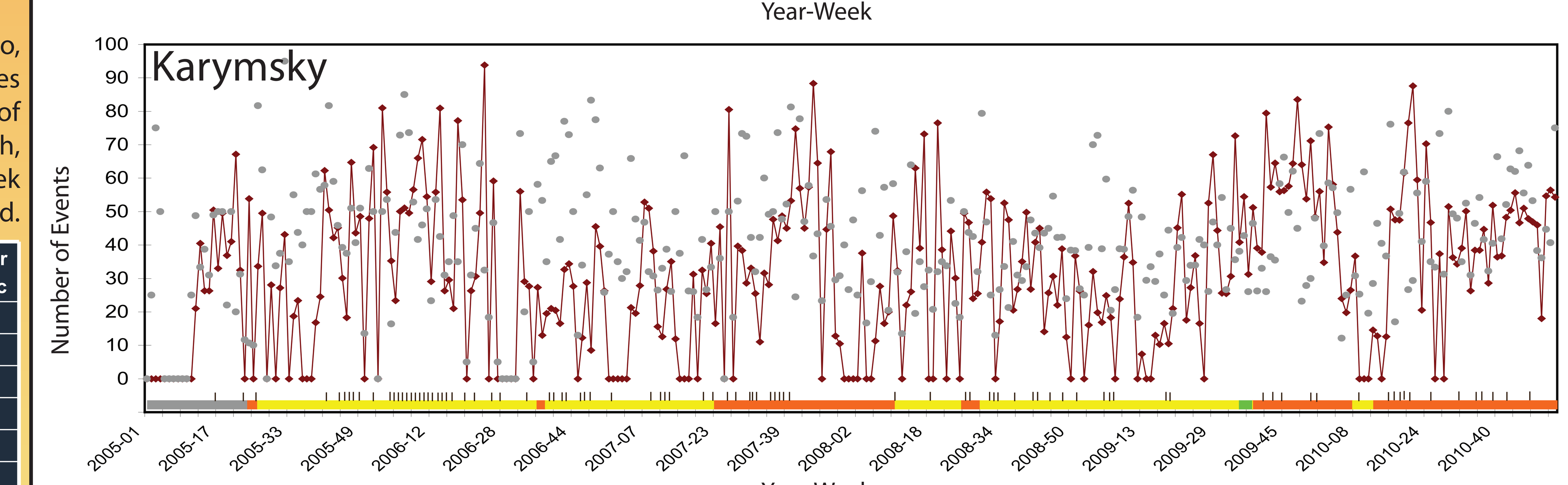
Shishaldin is, in terms of this study, a quiet volcano. For the analyzed period there were only 58 thermal anomalies and 14 reported ash signals. However, the seismic record tells a different tale. Shishaldin seismicity indicates that there are multiple small explosions daily, but the edifice geometry hinders satellite detection of almost all of these events.

Year	Collected Images	Viable Images	Thermal Anomalies	Weather Statistic
2008	8518	553 *(6.5%)*	6	31.64
2009	10022	694 *(6.9%)*	52	33.80
2010	5814	536 *(9.2%)*	0	31.26

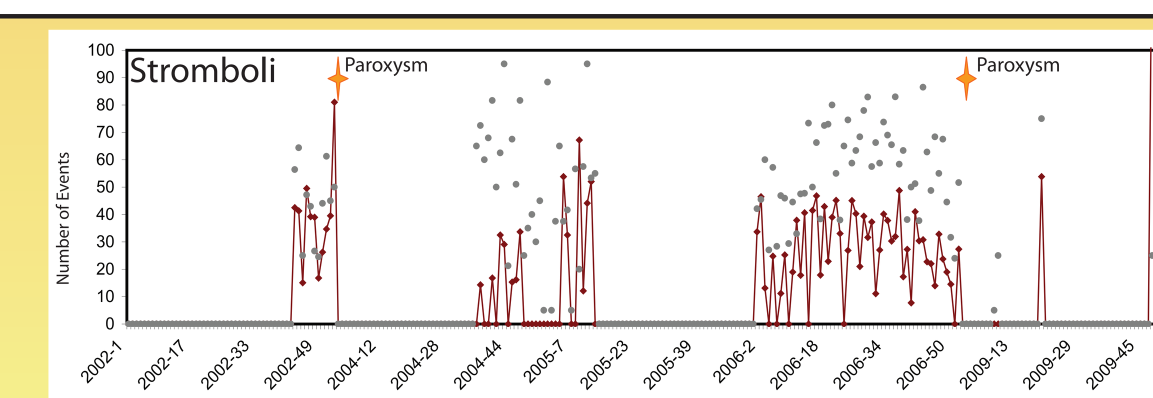


Karymsky is a very active volcano, frequently emitting detectable ash plumes (282 in analyzed period). The level of explosive activity is also consistently high, with an average of 35 events per week throughout the analyzed period.

Year	Collected Images	Viable Images	Thermal Anomalies	Weather Statistic
2005	1645	184 *(11.2%)*	70	37.21
2006	2848	271 *(9.5%)*	122	43.03
2007	3732	381 *(10.2%)*	141	42.12
2008	4480	434 *(9.7%)*	109	37.06
2009	5188	548 *(10.6%)*	200	40.08
2010	3863	538 *(13.9%)*	235	46.21



AVHRR and MODIS data from various periods of 2002-2009 was used (note data gaps in plot). The amount of data available for the Stromboli region was fairly limited. This is not an area commonly monitored and therefore images are not as rigorously collected by GINA (Geographic Information Network of Alaska) or AVO (Alaskan Volcano Observatory). However, the data is readily avaliable online and can be used to fill in gaps in the base-line model.



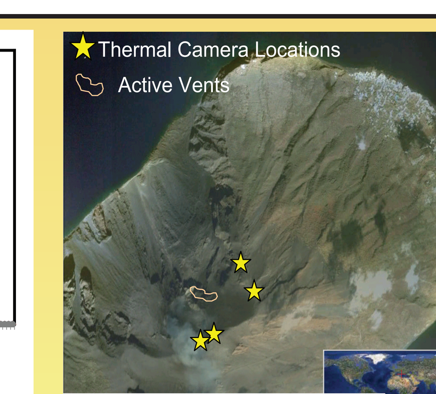


Figure 9: Stromboli Volcano

References

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Patrick, M.R., Harris, A.J.L., Ripepe, M., Dehn, J., Rothery, D.A., Calvari, S., 2007. Strombolian explosive styles and source conditions: insights from thermal (FLIR) video. Bull Volcanol. 69, 769-784.
Data Sources: GINA: http://www.gina.alaska.edu/ and AVO Remote Sensing Web Tools: http://avo.images.alaska.edu/tools/